Materials Systems Inc.

1–3 COMPOSITE ACCELEROMETER ARRAY

FINAL TECHNICAL REPORT

Office of Naval Research

Contract No. N00014-93-C-0238

Period of Performance

September 1, 1993 - September 30, 1994

Contractor:

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1.0 EXECUTIVE SUMMARY

The objective of this program was to fabricate prototype accelerometer devices from 1-3 PZT ceramic preforms and 1–3 piezoelectric composite material.

This program built upon the results of ONR Contracts N00014-92-C-0010 and N00014-93-C-0104, in which PZT ceramics injection molding technology and 1-3 PZT-polymer composite material fabrication were developed and scaled-up by Materials Systems Inc. (MSI).

Initially, this program was to be limited to accelerometers only. However, due to the early success of this effort in producing laboratory devices whose characteristics closely matched predicted specifications, it was mutually decided to conclude the effort with an ambitious first attempt at forming a combined accelerometer-actuator device. Therefore, with the concurrence of the Navy contract monitor, the quantities and configurations of the deliverables for this program were modified from those originally proposed to the following:

Two (2) 50 mm square bread-board accelerometers (Figure 1),
Two (2) 100 mm combined accelerometer-actuator devices, and
One (1) 250 mm accelerometer-actuator panel (Figure 2).

These devices were fabricated by MSI and delivered to the Naval Research Laboratory, Washington, DC, for test and evaluation.

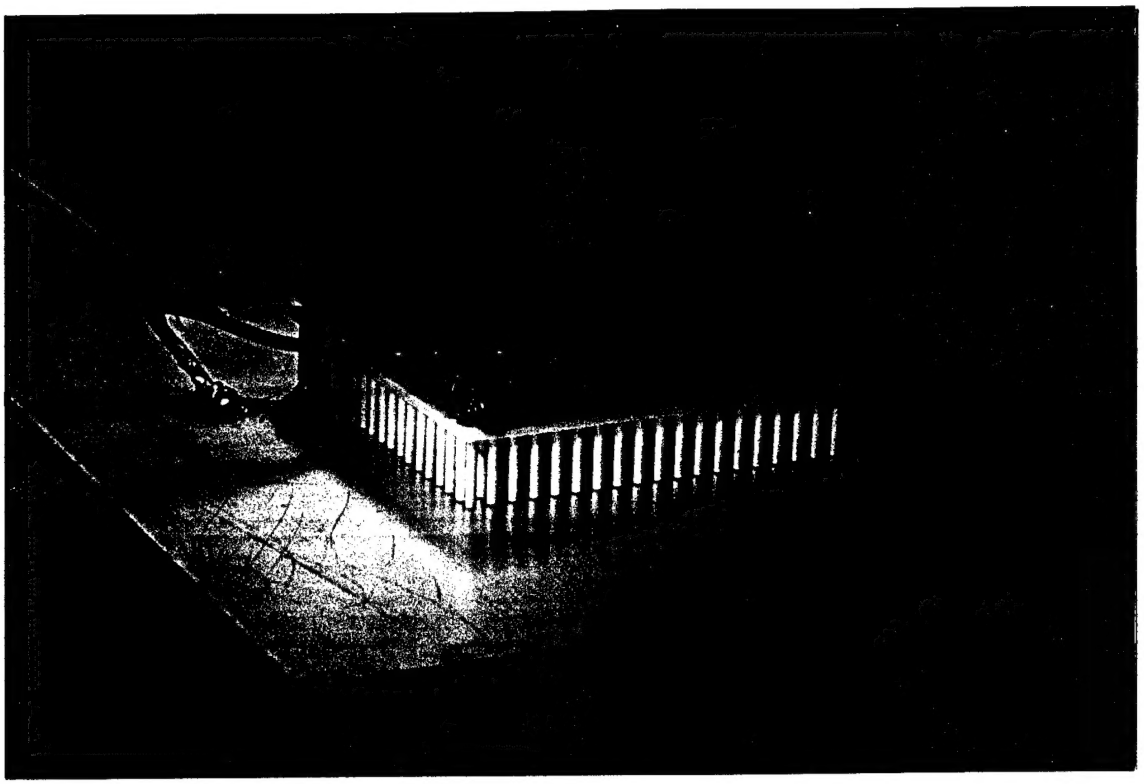

Figure 1. Breadboard accelerometer fabricated by MSI using an injection molded PZT preform for the active elements.

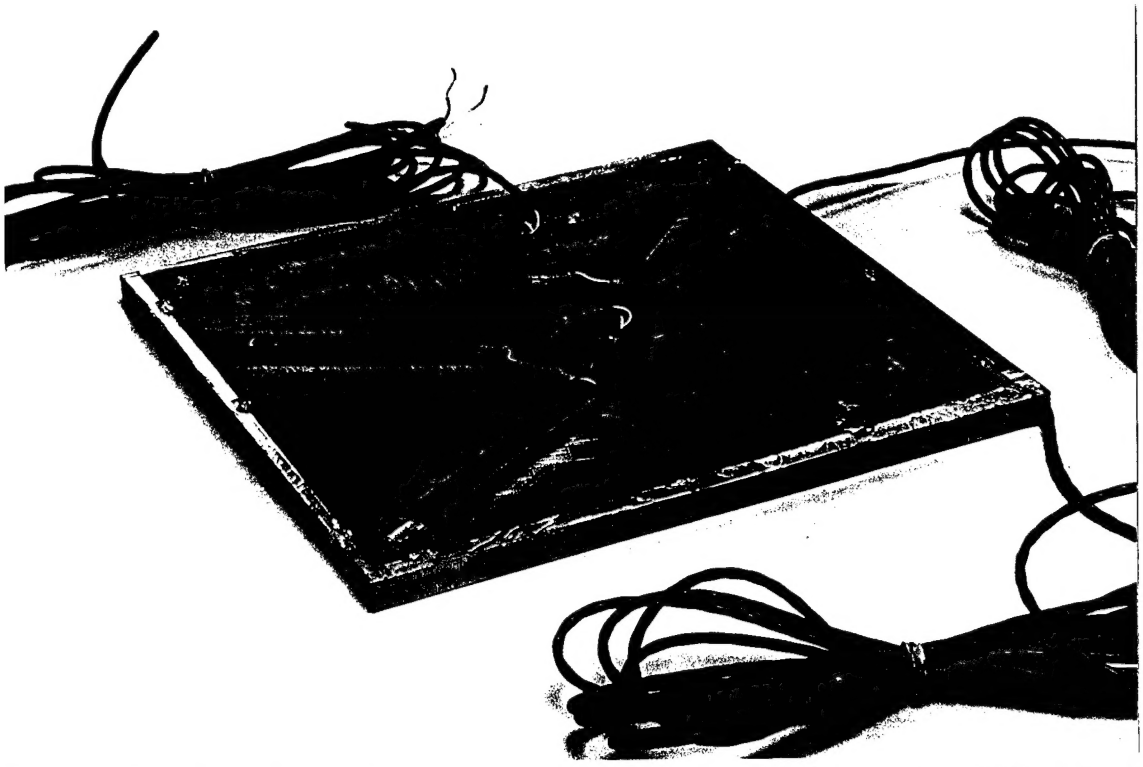

Figure 2. 250 mm accelerometer-actuator panel fabricated by MSI with six 25x100 mm accelerometer islands incorporated in a 1-3 composite actuator.

2.0 TECHNICAL DISCUSSION

Based on a concept suggested by the Office of Naval Research, Materials Systems Inc. (MSI) undertook to fabricate accelerometer devices utilizing 1-3 composite configurations. Under separate but related ONR funded programs (Ref.1,2), MSI has demonstrated a ceramics injection molding process for producing net-shape PZT preforms, such as that shown in Figure 3.

The dimensions of the PZT-5H preform are given in Table 1. The piezoelectric d_{33} values measured on individual PZT rods averaged 657 $x10^{-12}$ m/V with a standard deviation of 9.6 percent. The dielectric constant of the material was 3200.

Table 1: Dimensions of Sintered Injection-Molded PZT-5H Preform

Base plate	49.15 x 49.15 ($\pm$0.05) mm
Fiber length	7.9 mm
Fiber mid-point diameter	1.15 mm
Fiber spacing (center-to-center)	2.59 mm
Fibers per preform	361
PZT volume fraction	15%

2.1 Breadboard Accelerometers

With a poled injection-molded PZT preform as the building block, two breadboard accelerometer devices were fabricated and delivered to NRL-DC on October 13, 1993. Figure 4 is a schematic description of the breadboard accelerometer. The free ends of the PZT rods were bonded to a copper-plated GRP board using either silver epoxy or solder. A lead weight was bonded to the baseplate of the ceramic preform with silver epoxy. Wires were soldered to the GRP board and to a copper tab embedded in the silver epoxy bonding the lead weight to the ceramic baseplate. The completed breadboard device is shown in Figure 1.

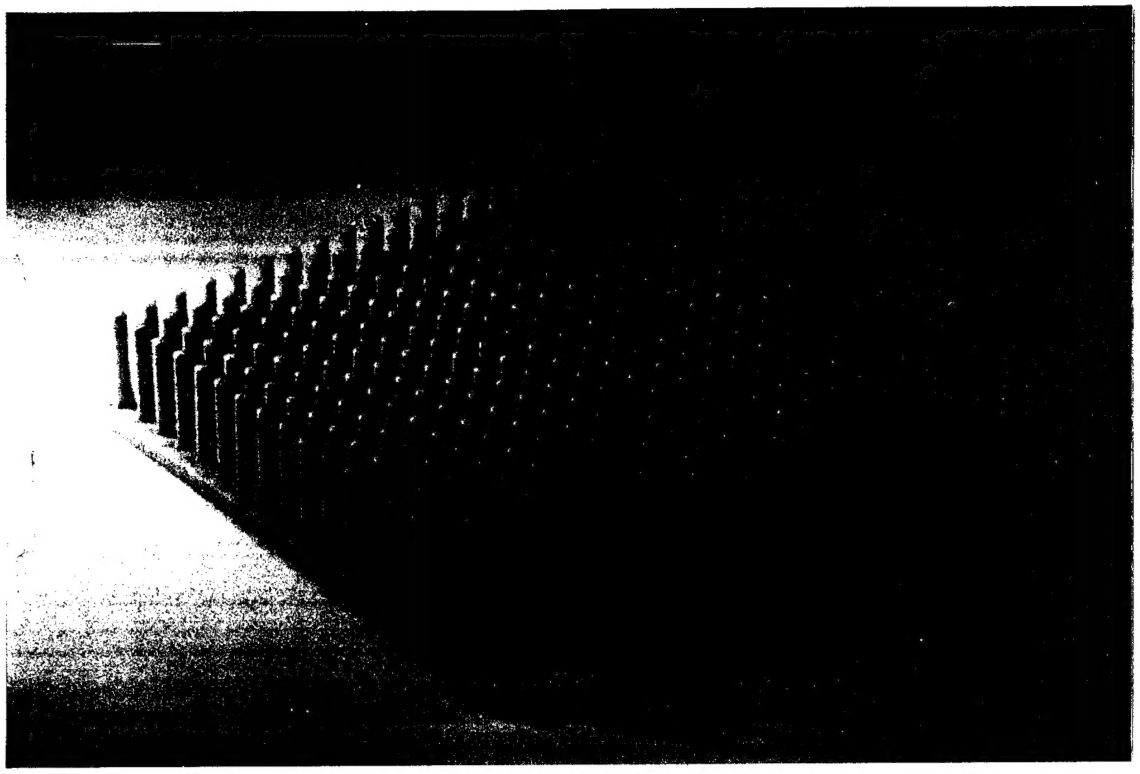

Figure 3. Sintered net-shape PZT preform, consisting of 361 PZT rods, each measuring 1.1 mm diameter and 7.9 mm long, on an integral base plate.

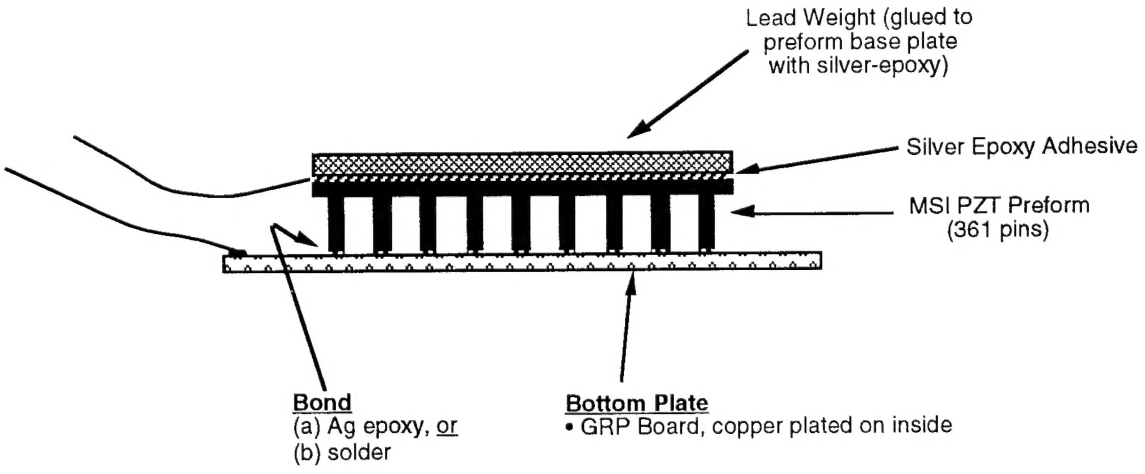

Figure 4. Schematic description of the breadboard accelerometer.

Table 2 lists the characteristics of the breadboard accelerometers delivered in this program.

Table 2: Breadboard Accelerometer Characteristics.

Device	Rod Length (mm)	Lead Weight (g)	Bonded to GRP with:
1.2	7.9	66	silver epoxy
1.3	7.9	91	solder

The sensitivity of breadboard device 1.3 was measured by NRL-DC. The measured sensitivity was approximately 500 mV/g – in good agreement with prediction (Ref.3).

2.2 100 mm Accelerometer-Actuator Devices

With the concurrence of the Navy contract monitor, the basic accelerometer design was fixed as shown in Figures 1 and 4. In addition, based on the early success in producing devices whose characteristics closely matched predicted specifications, it was mutually decided to redirect the effort to fabricating combined accelerometer-actuator devices.

Two (2) 100 mm accelerometer-actuator devices were fabricated and delivered to NRL-DC on June 30, 1994. These devices have an accelerometer located in the center of a 100 mm square 1-3 PZT-polymer composite actuator.

Device SS-2 has a free standing accelerometer, similar to the previous breadboard devices, inserted into a square cut-out in the actuator. This device is shown in Figure 5. NRL-DC has measured the total coupling in air between the actuator and accelerometer portions to be approximately -47 dB, a promising result for the initial device.

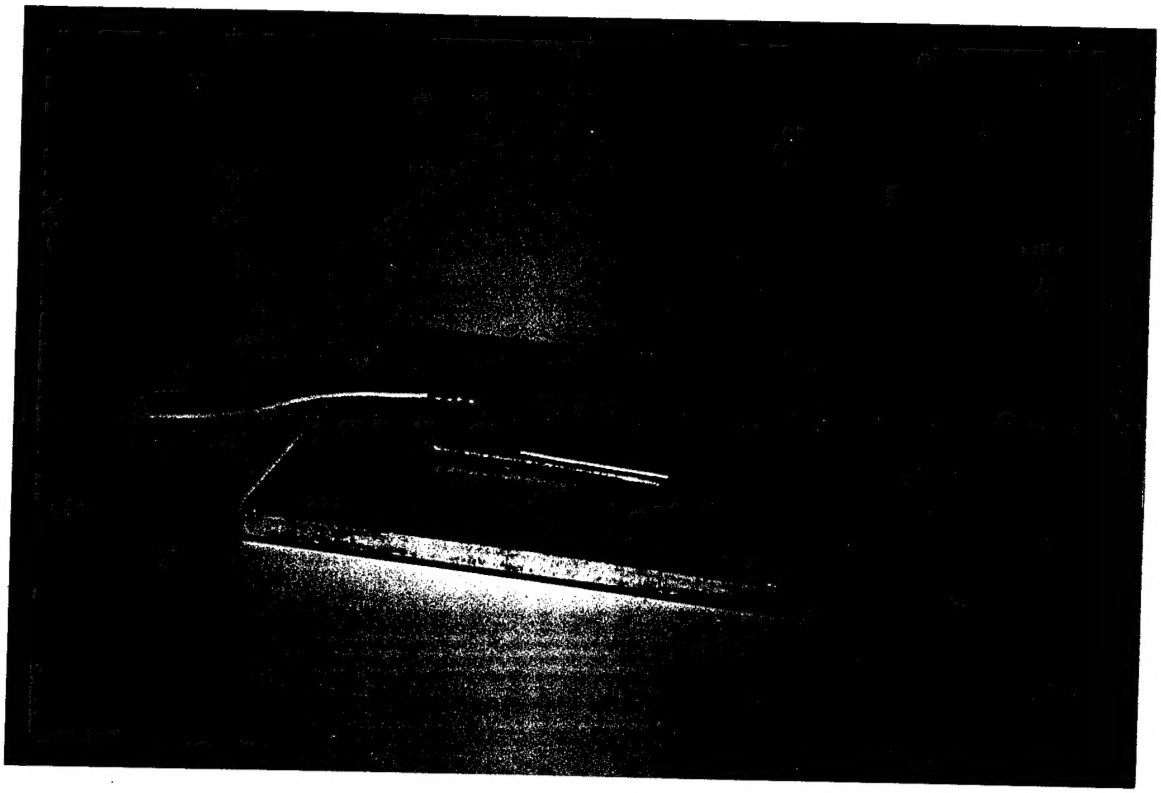

Figure 5. 100 mm accelerometer-actuator device SS-2, consisting of a 50 mm square free-standing accelerometer fitted into a cut-out in the 1-3 composite actuator.

Device SS-6 has a 57 mm diameter accelerometer made by cutting a circular groove through the top face plate, composite, and bottom electrode of a standard MSI SonoPanel 1-3 composite transducer and bonding a lead weight to the top face plate. Figure 6 shows a photograph of the device prior to attaching the wires and lead weight.

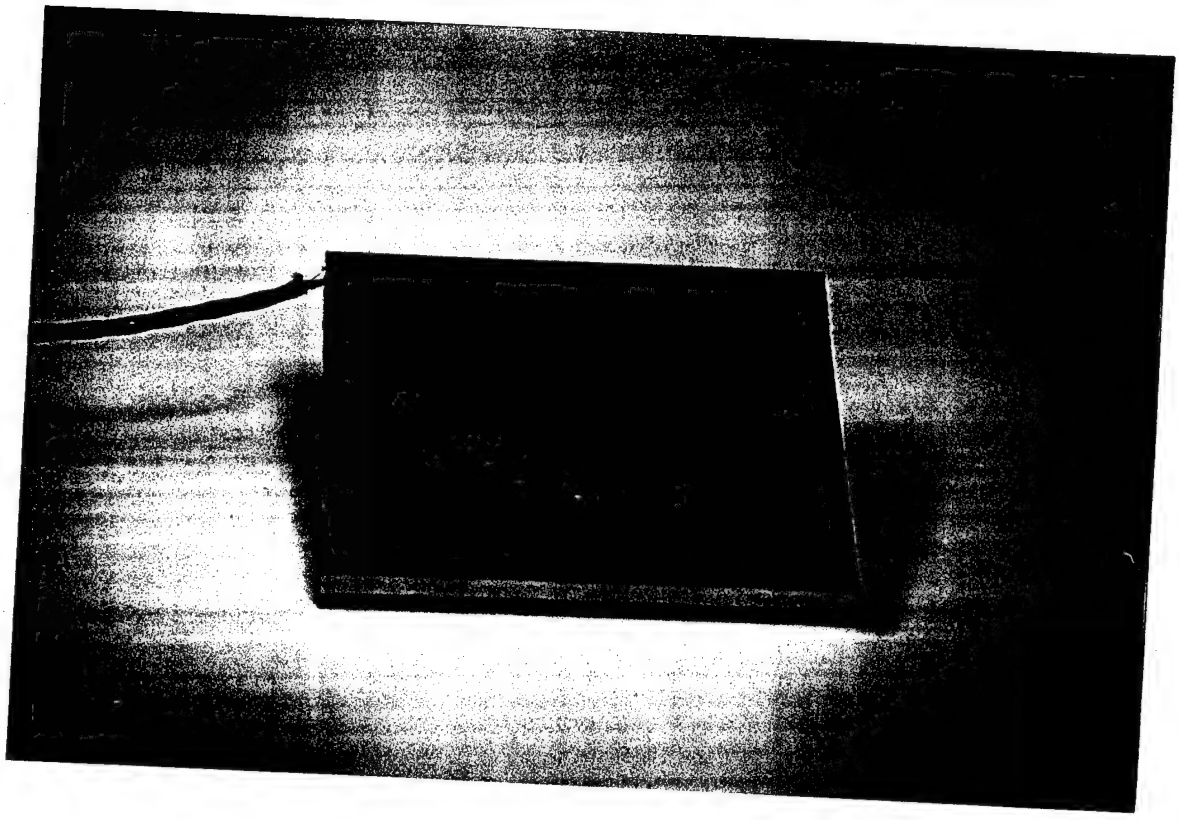

Figure 6. 100 mm accelerometer-actuator device SS-6, prior to attaching the wires and lead weight.

Schematic descriptions of the two devices are given in Figures 7 and 8. Accelerator area and lead weight are approximately the same for both devices. Specific characteristics are given in Table 3.

Table 3: 100 mm Accelerometer-Actuator Characteristics.

Device	Rod Length (mm)	Lead Weight (g)	Comment
SS-2	7.9	93	50 mm Square Free-standing accelerometer
SS-6	6.3	99	Circular, 57 mm dia. 1-3 PZT-polymer accelerometer Rods imbedded in polyurethane

2.3 250 mm Accelerometer-Actuator Panel

Based of technical discussions between MSI and NRL-DC, a design for a full scale accelerometer-actuator panel was developed. The basic design is similar to that of device SS-6, in that accelerometer islands are created by cutting narrow slots through the top face plate, 1-3 composite, and bottom electrode.

For the full-scale panel, it was decided to use several rectangular elements in a non-uniform arrangement. The objectives were to enhance the area averaging of the accelerometers, minimize lateral diffraction effects that might occur between accelerometers arranged parallel to one another, and minimize the span of actuator dead space.

Figure 9 shows the accelerometer layout for the 250 mm panel. The design consists of six (6) accelerometer islands each measuring 25x100 mm, covering a total of 12 percent of the panel. This pattern was laid out on a 250 mm SonoPanel transducer with 2.4 mm thick GRP face plates. The slots (approximately 3 mm wide) were then milled to form the islands. Figure 10 shows the 250 mm panel after milling the islands.

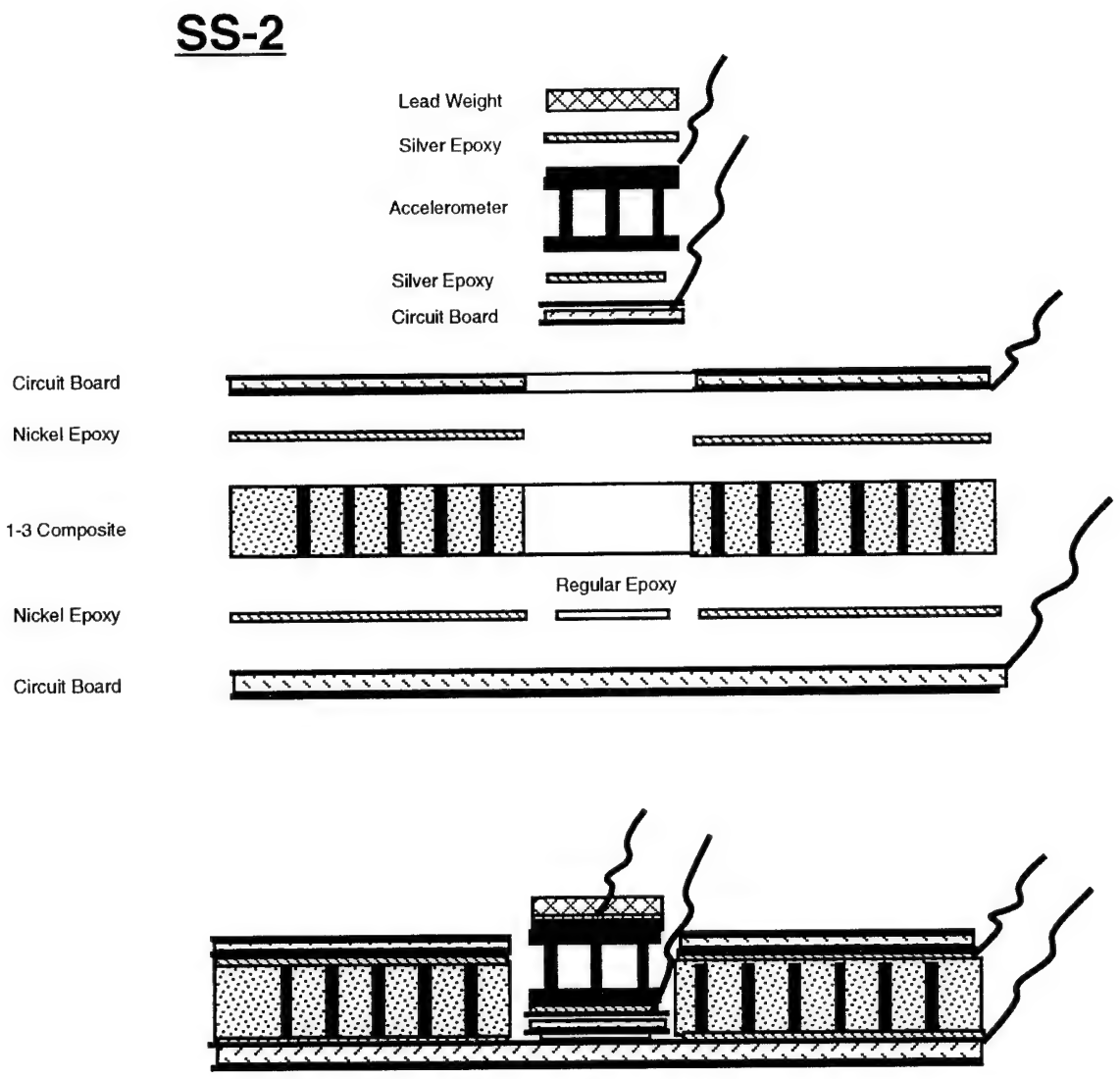

Figure 7. Schematic description of device SS-2.

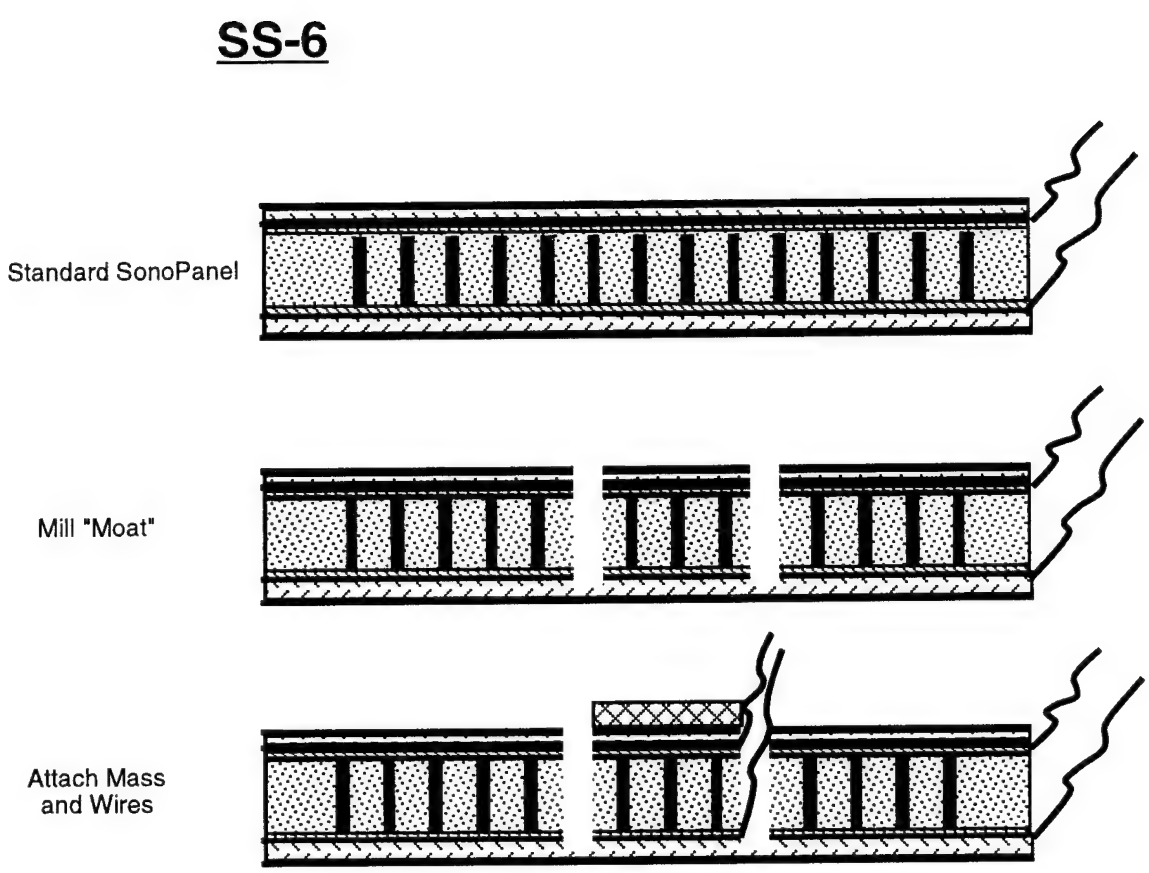

Figure 8. Schematic description of device SS-6.

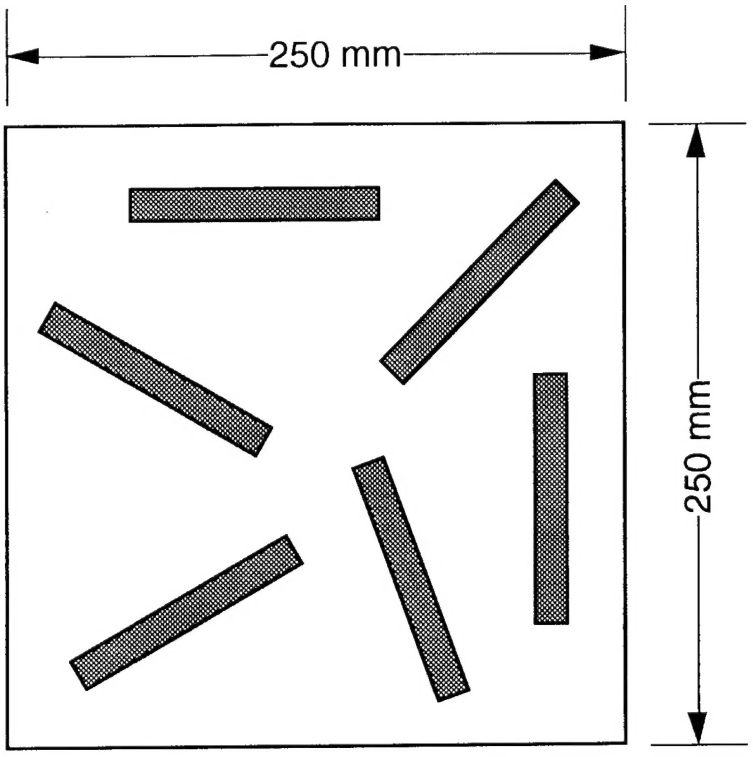

Figure 9. Accelerometer layout for the 250 mm panel. Six quasi-randomly arranged 25 x 100 mm accelerometer islands occupy 12 percent of the panel area.

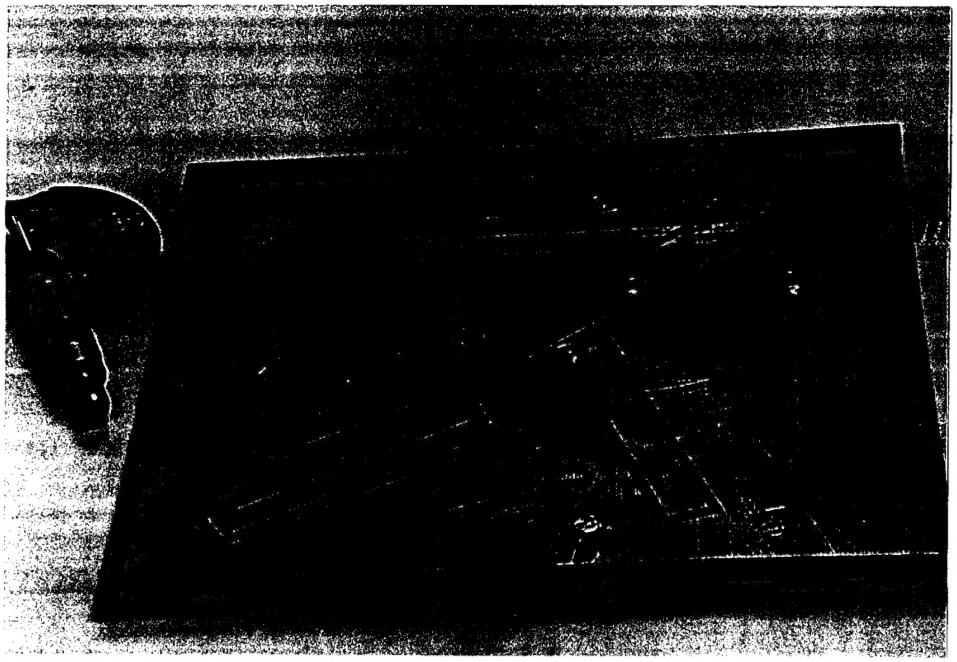

Figure 10. 250 mm panel after milling the accelerometer islands.

Most of the edge area of 3 of the 6 accelerometer islands was shielded with copper foil, with the objective of minimizing electromagnetic interference (EMI) from the relatively high drive voltages to be applied to the actuator portion of the panel. The shielding was soldered to the copper plating on the outer surface of the top face plate, which was in turn connected to the outer plating on the bottom face plate via the outer edge shielding on the panel itself. Figure 11 shows a close-up view of the shielding of one of the accelerometer islands as well as the edge shielding on the panel itself.

The three EMI-shielded accelerometer islands and the three unshielded islands were wired in parallel using 2-conductor coaxial shielded cable. The cable shield was soldered to the EMI shielding. Figure 12 shows some detail of the electrical connections.

To complete the 250 mm accelerometer-actuator panel, lead masses each weighing 53 ($\pm$1) g were bonded to the individual accelerometer islands with a commercial epoxy. The finished 250 mm panel was shown previously in Figure 2. This device was delivered to NRL-DC on September 12, 1994.

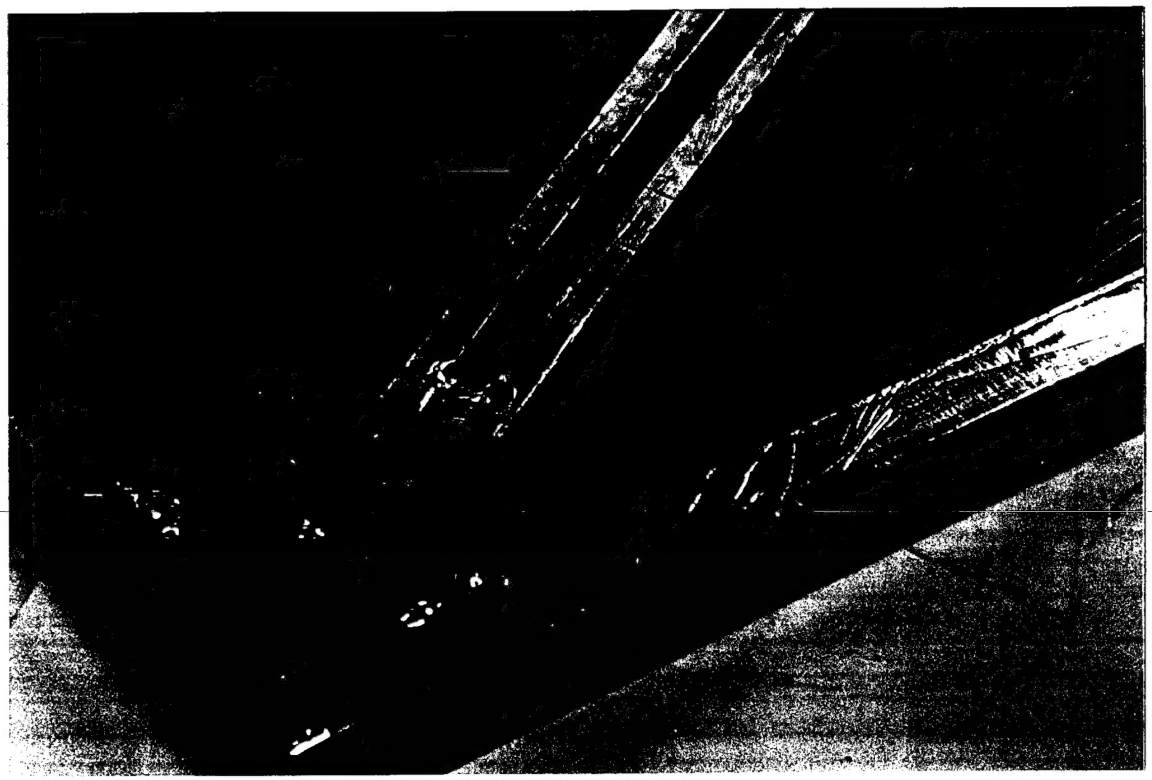

Figure 11. View of the shielding of one of the accelerometer islands and edge shielding on the panel itself.

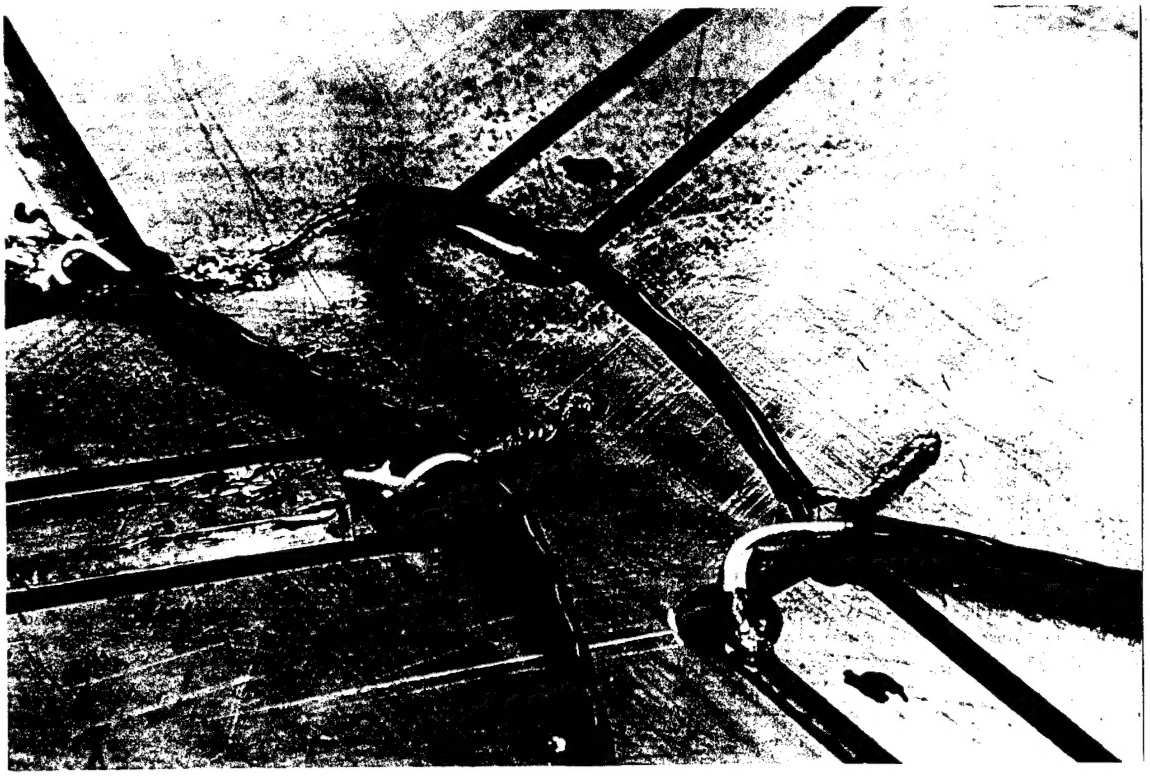

Figure 12. Accelerometer wiring detail for the 250 mm panel.

3.0 REFERENCES

1. Materials Systems Inc., Fabrication of Piezoelectric Ceramic/Polymer Composites by Injection Molding, Final Report Contract N00014-92-C-0010, April 15, 1993

2. Materials Systems Inc., Manufacturing Demonstration of Large 1–3 Piezoelectric Ceramic/ Polymer Composite Panels using Ceramic Injection Molding, Final Technical Report, Contract No. N00014-93-C-0104, Sept.30, 1994

3. R. Corsaro, Naval Research Laboratory, personal communication, Aug. 5, 1994